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Maximizing percent in limits for chemistry parameters at Wisconsin Public Service Corporation Weston Station

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MAXIMIZING PERCENT IN LIMITS FOR CHEMISTRY PARAMETERS AT WISCONSIN PUBLIC SERVICE CORPORATION WESTON STATION

by

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APPROVAL PAGE

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CASE SUMMARY

The laboratory group at Wisconsin Public Service Corporation's Weston Station has experienced difficultity maintaining all chemistry parameters within desirable ranges. This paper identifies which parameters have the greatest negative impact on the overall chemistry program.

After identification of the problem parameters, the paper addresses causes for these parameters being out of the prescribed ranges. This is done through use of various statistical tools such as correlation charts, time function graphs, Pareto diagrams, and cause and effect diagrams.

Because the paper identifies several problem parameters, the difficulties experienced by the laboratory group requires several solutions. The paper covers those changes in communications, procedures, and resource committment needed to solve the problem of parameters frequently falling outside the desired ranges. The paper also addresses certain solutions which should not be implemented (and why). Finally, the paper presents the costs and benefits of executing the proposed solutions and a plan of implementation.

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SECTION 1
INTRODUCTION

Wisconsin Public Service Corporation (WPSC) is headquartered in Green Bay, Wisconsin. The company employs over two thousand people working to provide electricity and natural gas to approximately three hundred fifty thousand customers in north central and north east Wisconsin. In recent years, the company has diversified into several areas, including facilities management software (for record keeping and map generation of electrical and gas distribution equipment) and Norlight (fiber optic communications).

WPSC owns several electrical power production stations including coal fueled boilers, one nuclear fueled boiler, natural gas fired combustion turbines, and hydroelectric stations. The Weston station, near Wausau, Wisconsin, has three coal fired boilers and two gas turbines. Large differences in production costs dictate running the coal fired boilers for base-load operation (near continuous) and utilizing gas turbines only when needed due to unavailability of purchase power and high customer demand (peaking operation).

Simply stated, coal fired boilers turn thermal energy (heat from combustion of coal) to mechanical energy (rotation of a turbine by steam produced from heat release in coal) to electrical energy (movement of a conducting material through a magnetic field). Of course, operating and maintaining this equipment is not a simple matter. The Weston station requires 165 people, divided among several departments, working for the common goal of efficient and safe electricity production.

These departments include operations, mechanical maintenance, electricians, coal and yard, instrument and control, secretarial, janitorial, and laboratory. The laboratory group consists of four laboratory attendants (responsible for manual analyses, analyzer maintenance, and analyses results compilation) and one technician (responsible for effective operation of auxiliary systems which impact chemistry).

One of the laboratory's primary charges is maintenance of appropriate system chemistry within the water (both liquid and vapor) portion of the power production cycle. Keeping water chemistry within prescribed purity limits insures that corrosion of expensive capital equipment can be kept to a minimum. The laboratory group performs purity determinations by measuring numerous impurity concentrations as well as several residual concentrations of chemicals added to maintain desirable conditions. The laboratory attendants place all data generated in a computer data base for computer and human analysis.

The computer gives a report card, in effect, regarding the degree of success the laboratory staff obtained meeting purity requirements. The report indicates, for each boiler (unit) and for each parameter, what percent of the measured parameters fell within the desired range for the month. The laboratory staff also determines overall effectiveness for each unit by taking the ratio of the sum of the number of analyses within limits to the sum of the number of all tests run. The express goal of the laboratory group is to maintain this overall percent in limit number at or above eighty percent for the oldest two units at Weston and at or above ninety percent for the newest unit. The Plant Chemist based these goals on percentages achieved by laboratory groups working for other utilities and on educated estimation of what is achievable given each unit's history (Fossil Operations and Maintenance Information Service [FOMIS], 1989). FOMIS is a privilege to which WPSC and many other utilities subscribe. The Plant Chemist used FOMIS reporting to review the in limit percentage goal for several utilities.

SECTION 2
DESCRIPTION OF SITUATION
General

The Weston station consists of three distinct units, each one capable of independent power production. Unit 1 was commissioned in 1954 and has a 60 megawatt (MW) capacity. The 75 MW Unit 2 dates to 1960. The newest unit (# 3) was commissioned in 1981 and is capable of producing 345 MW. Each of these units is unique in terms of water chemistry demands due to differences in usage patterns and operating pressures.

WPSC also operates several fossil fired units in Green Bay, WI at the Pulliam station. Two of the six units at Pulliam station are nearly identical to Weston units 1 and 2 with regard to capacity and operating pressure. These units provide the basis for excellent comparative studies.

Due to changing pressures, temperatures, and water flows during load changes, system chemistry is best maintained by the laboratory staff under steady load conditions. Both unit 1 and unit 2 see heavy load swings, with unit 1 subject to frequent shut-downs as well (due to demand drop-off after evening lighting loads). These load swings cause chemistry upsets which are very difficult to counteract manually. Unit 3 is not subject to load swings to the same extent as the older units. In addition, units 1 and 2 are not instrumented nearly as well as unit 3 due to the vintage differences. The instrumentation and control arrangements available at unit 3 allow the unit to respond automatically to chemistry upsets with no operator intervention required.

Plant Organization

The Weston station has a pyramid-shaped hierarchical structure with the Plant Manager ranked highest. Reporting to the Plant Manager are the Superintendent of Operations, the Superintendent of Maintenance, the Technical Supervisor, and the Building Services Supervisor. The operations group is charged with day to day running of the plant equipment. The Superintendent of Maintenance supervises the groups charged with repair of equipment and safety coordination. The Technical Supervisor manages the instrument and control, performance, and chemistry groups. The Building Services Supervisor oversees secretarial, clerk, and labor relations areas.

Laboratory

The chemistry or laboratory staff consists of the group supervisor (the Plant Chemist), one auxiliary equipment technician, and four laboratory attendants. The Plant Chemist position requires a degree in chemical engineering or chemistry and reports to the Plant Technical Supervisor. The technician for auxiliary equipment (Results Technician) requires power plant experience related to systems used in maintaining system chemistry (such as demineralizers and waste water treatment equipment). The attendants are generally promoted from operations personnel. Two of the four attendants have a naval background related to operating shipboard boilers and maintaining proper chemistry in them.

Historical work loads for laboratory attendants have mandated one full time person stationed at units 1 and 2 and three attendants stationed at unit 3. With implementation of additional analyzers and requirements for additional laboratory test work at the older two units, the three analysts stationed at unit 3 have spent more time at units 1 and 2 than was true previously.

Communications between the Plant Chemist and the laboratory group are handled during short (15 - 30 minutes) meetings each morning and during discussions between the Plant Chemist and individual laboratory attendants. Each month, the Plant Chemist prepares a formal written station chemistry report. The Plant Chemist circulates this report to plant management for their review. Each week, during the plant staff meeting, the Plant Chemist presents any unusual laboratory activities to plant management. These activities might include equipment inpection observations or non-routine test results. Through the station chemistry report and weekly verbal reports, the Plant Chemist communicates to management the status of laboratory activities.

Besides running routine tests and making appropriate changes in chemical dosage and boiler operating conditions, attendants also respond to emergency conditions after normal working hours either by reporting to the plant site for test work or relaying instructions to operations staff. The Plant Chemist has developed special alarm response procedures for the operations personnel to utilize in the absence of laboratory staff. These procedures often eliminate the need (and cost) of calling in a laboratory attendant.

Maintenance of appropriate system chemistry at Weston requires the application of most management functions. Specifically, managing the chemistry process mandates proper planning, organizing, controlling, and leading techniques. By examining and applying these functions, management is better able to deal with the complex task of maintaining appropriate chemistry.

Through proper planning, the Plant Chemist makes valuable decisions regarding the future. These decisions include commitment of resources and prioritizing of activities. Planning also includes determination of measurable objectives. Examples of operational planning include budgeting for replacement resin (similar to that found in home softener systems), considering its age and condition or training and budgeting for testing required for anticipated regulation changes. Other measurable operational goals might include keeping overtime at or below a certain number of hours or providing a certain number of hours of training to each laboratory attendant over the upcoming year.

Having developed plans, the Plant Chemist must design a structure of human and material resources to accomplish the laboratory group goals set during planning. Organizing is the process of creating such a structure. The Plant Chemist must determine the scope of activities for each person in the group and make determinations (with the group's input) on how limited resources (the available operational budget) will be spent. Diversity, size, and breadth of operations of the laboratory group enables the Plant Chemist to determine the best organizational structure for the laboratory group.

Leading refers to influencing others to perform duties which will achieve the objectives. The Plant Chemist must consider communication style and motivation of the group. For example, the Plant Chemist must decide to lead by example (by performing analytical tests personally) or by description of procedures only (to avoid potential union agreement problems).

Finally, laboratory management must control the group activities. This can be done by determination of acceptable standards, measuring the group performance against the standards, and taking action as required when performance does not meet standards.

The four management functions of planning, leading, organizing, and controlling are related and not necessarily performed in sequence. To be most effective the process is repeated to accommodate changing conditions in the environment. To successfully address the problem(s) (see SECTION 3), the Plant Chemist must consider changes in the ways each of these managerial functions are performed. SECTION 5 covers these potential changes.

SECTION 3
PROBLEM IDENTIFICATION

As noted above, the chemistry group monitors the percentage of chemistry parameters which fall within defined limits. The problem is the laboratory staff has been unable to maintain the overall performance number above eighty percent for the older two units. The staff does typically achieve the ninety percent performance sought for the newest unit. As noted in the previous section, the Plant Chemist determined these target percentages through review of FOMIS data and Weston unit history.

Of course, there is a cost impact associated with not achieving eighty percent in limits. The cost is related to unit outages caused by either corrosion or fouling of the equipment. The majority of the costs of these forced outages are related to lost revenue due to inability to produce power. A smaller part of the cost comes from replacement equipment and labor for equipment repairs. For unit 1, lost revenues for a one day outage would be approximately $30,000 and two times this amount for unit 2. Unfortunately, the laboratory group has no method available to relate percent in limits with outage probabilities, as the data does not exist. The best the group can do is to aim for the highest percentage deemed attainable given the unit's operational history. In the case of Weston's units 1 and 2, the laboratory staff has set the target percentage to eighty percent. The problem, for the laboratory staff, of achieving greater percent in limits for Weston water chemistry is basically one of quality improvement of a process.

SECTION 4
PROBLEM ANALYSIS
General

In this case the process is not as straightforward as, say, an assembly line with known starting and ending points, but one can still envision the process. A useful way to picture the process is to view it as the circular route of water preheated in the feedwater section, converted to steam in a boiler, reduced in pressure through a turbine, converted back to water in the condenser, then sent back to the feedwater section. Removal points (boiler blowdown to remove solids) and addition points (clean makeup water to the condenser) exist by necessity. In addition to the water and equipment, personnel, such as operators and laboratory attendants, and consumer demand (forcing system condition swings) also are part of the process.

The first step, then, in this quality improvement process is to effectively diagnose the problem. The statistical methods to do exactly that are readily available. In fact, statistical analysis of water chemistry parameters in limits is much easier than more qualitative processes such as training or safety programs because chemistry, by design, deals in numbers routinely.

The primary tools to be used in the problem analysis are run charts, Pareto charts, and cause and effect diagrams. Supporting these tools are linear regression, regression correlation, and prediction interval calculations. The graphical presentation of these methods is particularly valuable in visualizing data with the purpose of spotting trends and correlations.

Figure 1 and Figure 2 are run charts (or time series graphs) for the overall chemistry performance for Weston 1 (W1) and Weston 2 (W2) respectively. Both graphs show a trend in an upward direction. Apparently, the process is not a stable one. This is, of course, desirable since the

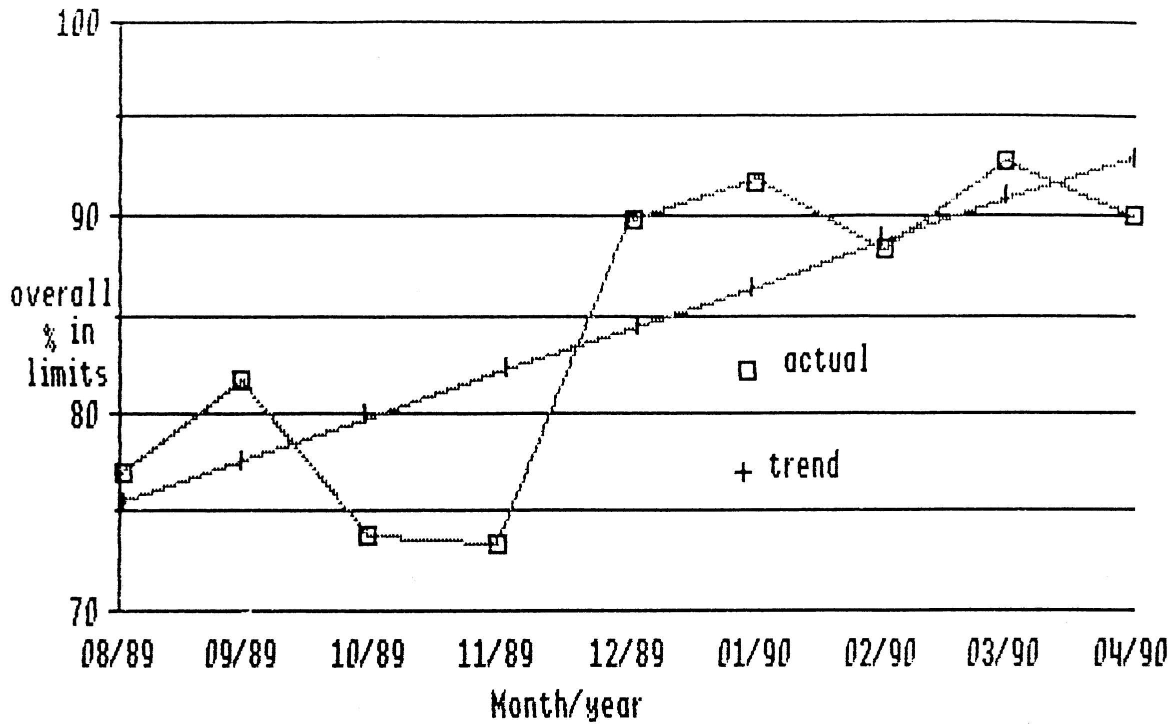

Figure 1. Weston 1 Overall Chemistry Performance

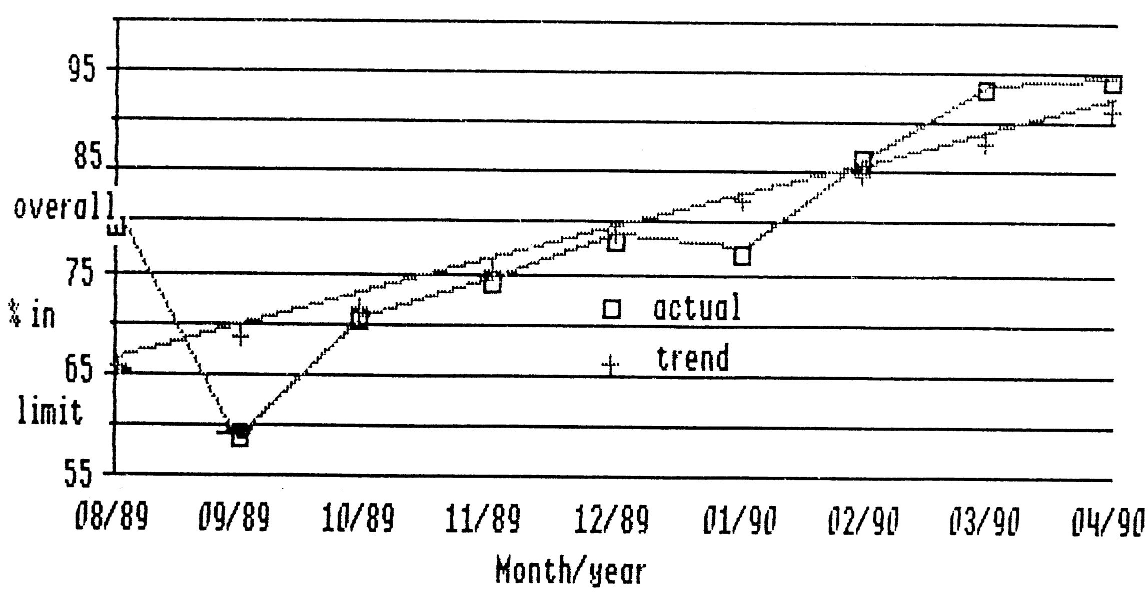

Figure 2. Weston 2 Overall Chemistry Performance

instability is positive, but it is also necessary to know the reasons behind these trends.

Both graphs also include a trend line. This is a straight line least squares fit of the data. The regression coefficient (R^2) for W1 is 59% and for W2 it is 61%. This indicates that 59% and 61% of the data (overall percent in limits) can be explained as a function of time. While time, per se, is not an independent variable for chemistry performance, these figures indicate a high probability that recent changes in the process are responsible for variation in the data.

The laboratory staff computes the overall chemistry performance parameter from all the individual performance parameters. Therefore, it is logical to construct time series graphs for each of the individual parameters and look for changes or trends. There are nineteen individual parameters each for the two units.

Weston 1

Examination of all nineteen parameters for W1 revealed only two which are significantly affecting the overall percent in limits parameter in a negative direction. These two are oxygen scavenger concentration in boiler water and boiler water sodium to phosphate ratio. The other seventeen parameters were found to either be increasing to eighty percent in limits or above, or were already exceeding eighty percent in limit. In general, for those parameters which show significant recent improvement, the increase can be explained by the December 1989 switch to a new oxygen scavenger (the nature of which is discussed below). Since chemistry staff interest is mostly in parameters which negatively impact the overall performance, the following analysis is restricted to the two negative parameters mentioned above.

Boiler Water Oxygen Scavenger

Figure 3 shows the run chart for the two parameters over the same time period as plotted in Figure 1. Boiler water oxygen scavenger concentration is consistently below 60% with one month near 10%. Data review revealed this concentration was often over the upper limit of 0.5 parts per million. Oxygen scavenger, as the name implies, is a chemical fed to the feedwater system to react with and remove dissolved oxygen.

Dissolved oxygen will, if left unchecked, react with iron components to form rust. Too much oxygen scavenger in boiler water can contribute to excess dissolved solids and organics which in turn can be carried with steam into the turbine where these impurities may be deposited on turbine blading. Turbine blade deposits can reduce turbine efficiency in a manner similar to ice on an airplane wing. In addition, excess oxygen scavenger can break down to form carbon dioxide, which in turn acts to reduce boiler water pH (a measure of corrosivity). Low pH leads to greater corrosion.

Boiler Water Sodium to Phosphate Ratio

Also shown in Figure 3 is the boiler water sodium to phosphate ratio individual parameter. The percent in limits for this parameter has taken a dramatic downturn during the last two time periods plotted. For W1, the upper limit on sodium to phosphate ratio is 3.0. At conditions above 3.0, the boiler is susceptible to conditions of localized extremely high corrosivity. These localized conditions can directly attack boiler tubing in a mechanism called caustic gouging. An increasing number of test results show the sodium to phosphate ratio to be higher than 3.0.

Weston 2

A look at individual parameters for W2 shows a somewhat bleaker picture than for W1. Six of nineteen parameters warrant a closer look based on negative trends or consistent in limits percentages less than 80%. The six are boiler water sodium to phosphate ratio (same as W1), condensate ammonia, condensate specific conductivity, feedwater oxygen scavenger, saturated steam conductivity, and superheated steam conductivity. Figures 1 and 2 also indicate more of a problem with W2 then with W1 as evidenced by a steeper positive trend line for W1.

Boiler Water Sodium to Phosphate Ratio

Figure 4 shows three of the individual parameters for W2. Boiler water sodium to phosphate ratio has been at 50% or less over the last five time periods. Because W2 operates at higher pressure than W1, there is both an upper and lower limit for sodium to phosphate ratio. The goal is to keep the ratio between 2.3 and 2.6. Too high a ratio and the boiler may experience caustic gouging as explained above, too low and the tubes are susceptible to hydrogen (or acidic) damage. The in limits numbers have been low due to high ratios.

Steam Conductivities

Figure 4 shows steam conductivities (both saturated and superheated) and boiler water sodium to phosphate ratio. The laboratory staff has occasionally noted both conductivities at levels over the 2.0 micromho/cm upper limit. Over the seven month time period in Figure 4, saturated steam conductivity percent in limits has equaled or exceeded 80% only once. The same is true of superheated steam conductivity. Conductivity is a measure of water's ability to conduct an electrical current. The greater the conductivity, the greater the concentration of dissolved solids (Aschoff, Lee, Sopocy, and Jonas [1986]). As indicated above, high dissolved solids are

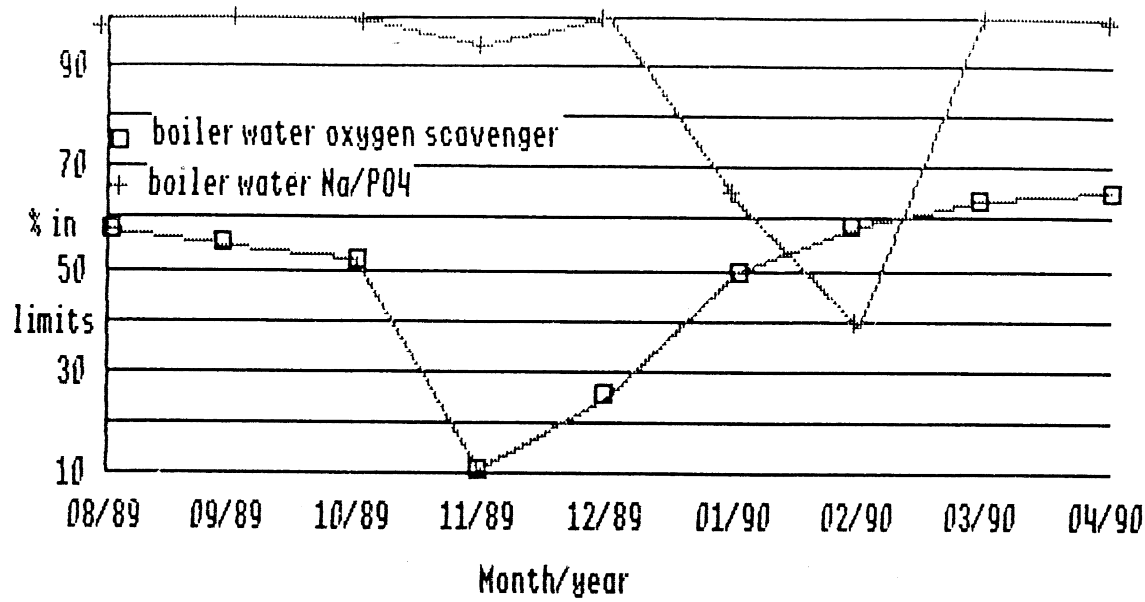

Figure 3. Weston 1 Individual Parameters

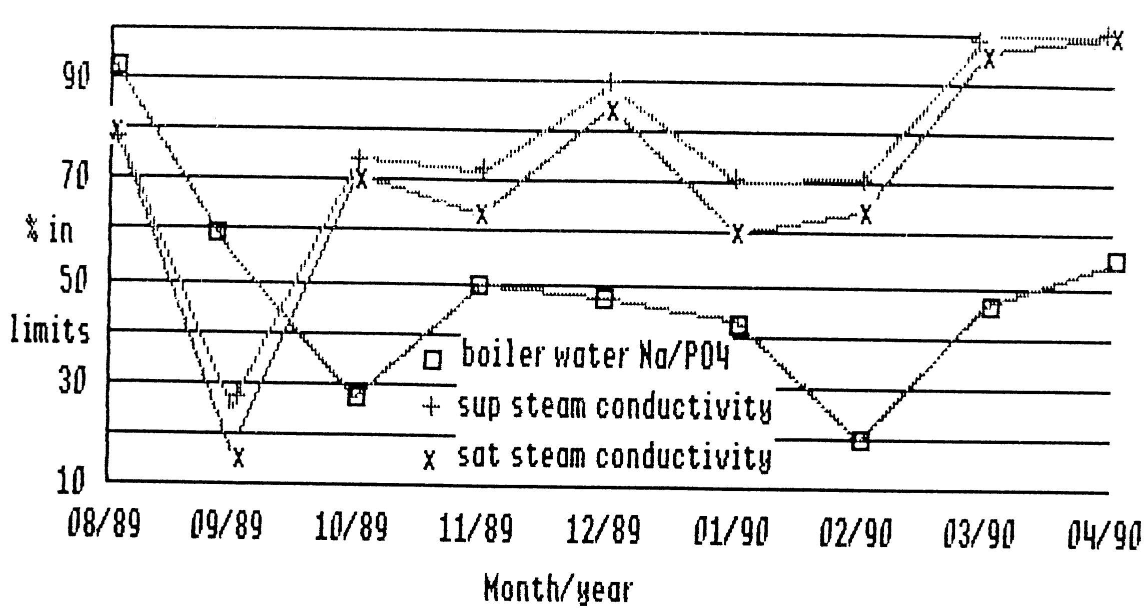

Figure 4. Weston 2 Individual Parameters

undesirable due to their tendency to come out of solution on turbine blading. High conductivity in steam is particularly harmful, because steam comes in direct contact with the turbine. Saturated steam is generated in the boiler steam drum. From the drum the steam is directed to the superheater and from the superheater directly to the turbine.

It is interesting to note the strong correlation between saturated and superheated steam conductivities. This can be seen in Figure 4, as the two trend closely together. Figure 5 is a scatter graph of the two parameters, which shows further evidence of the close relationship between saturated and superheated steam conductivities.

Condensate Ammonia

Figure 6 shows the remaining three parameters of interest for W2. These are condensate ammonia, condensate specific conductivity, and feedwater oxygen scavenger. Ammonia is formed primarily from nitrogen contained in the oxygen scavenger, which is eventually released through reaction and degradation. Ammonia (in combination with dissolved oxygen) is capable of reaction with any alloys containing copper. In this way, it acts to corrode condenser and feedwater heater materials. Figure 6 indicates during many months, only 70% or less of ammonia readings are within limits (less than 0.3 ppm). Since zero ammonia is desirable, there is no lower limit.

Condensate Specific Conductivity

Condensate ammonia is related to condensate specific conductivity. Ammonia is one species which contributes to conductivity so it is reasonable to see problems with conductivity given difficulty with high ammonia concentrations. Other species, though, such as sodium and calcium also contribute, so this parameter needs to be examined separate from ammonia.

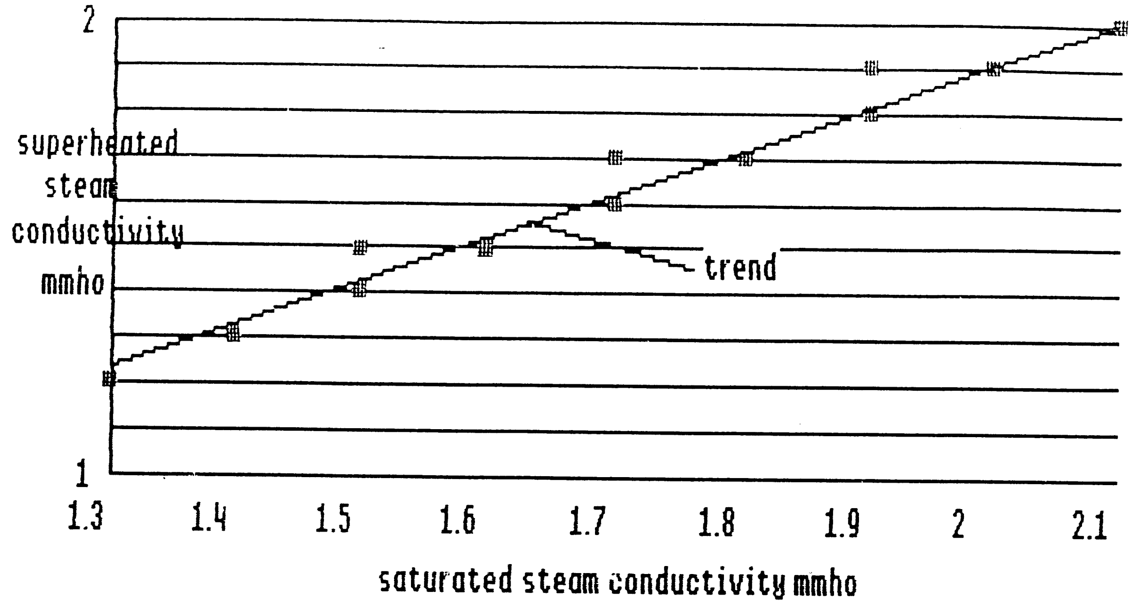

Figure 5. Weston 2 superheated steam conductivity versus saturated steam conductivity

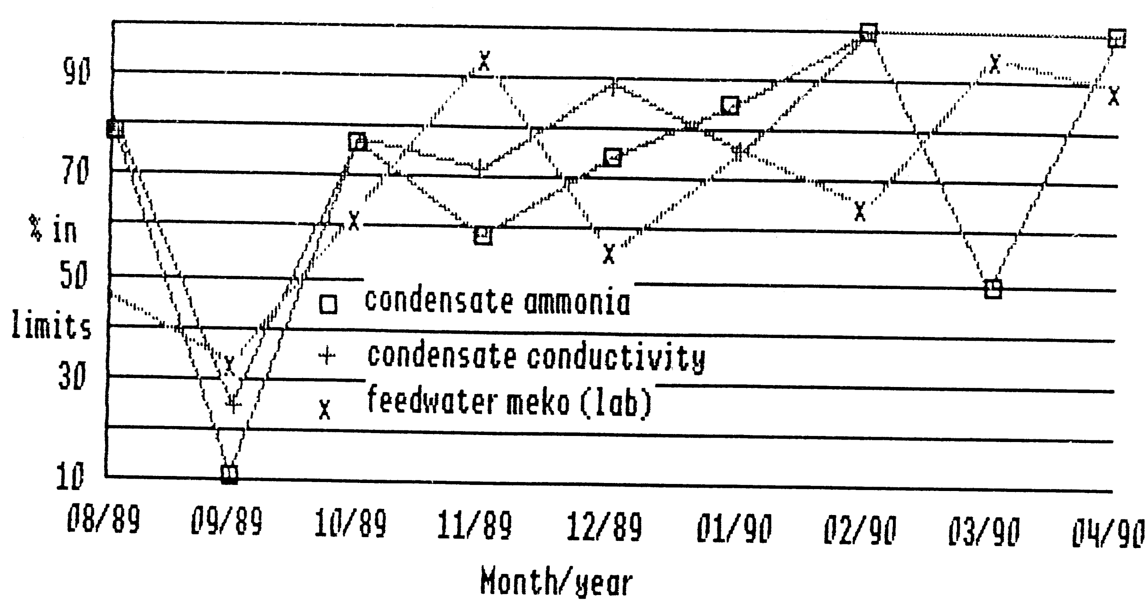

Figure 6. Weston 2 Individual Parameters

Conductivity, then, is a more general indication of impurity levels in condensate so some attention must be paid to species not directly measured.

Feedwater Oxygen Scavenger

In addition to condensate ammonia and conductivity, Figure 6 shows feedwater oxygen scavenger concentration. The percent in limits for the parameter ranged from a low of about 35% to a high of 93%. In all months plotted except one, the percent in limit was less than 80. Clearly, this parameter requires attention. Oxygen scavenger presence is important as explained above and is one of the critical chemicals added for proper corrosion control. The concentration of the oxygen scavenger is often at or near 0 ppm. This is dangerous, as the system then has little or no protection from corrosion associated with dissolved oxygen. Occasionally, the feedwater concentration will exceed the upper limit of 0.16 ppm with at least one instance of 0.2 ppm. This, too, is undesirable, because the excess can contribute to dissolved solids which puts the turbine at risk.

Pareto Analyses: Weston 1

Another useful tool in examining the problem with the overall chemistry performance characteristic is the Pareto Diagram. Figure 7 shows the Pareto of all nineteen individual parameters for W1. This diagram is useful for discovering if any parameters contributed substantially to the problem, i.e., finding those parameters with high contributions to reduction in the overall percent in limits for the unit. As evident by Figure 7, there are no clear "winners". The chart has a very "weathered" look, with most parameters contributing a small portion to the problem. The three largest contributors are boiler water oxygen scavenger, feedwater pH (analyzer), and feedwater pH (lab).

The problem with boiler water oxygen scavenger concentration showed up as a problem on the individual parameter run charts as discussed earlier. Since the Pareto shows the degree each parameter contributes to reduction in the overall percent in limits, boiler water oxygen scavenger concentration shows on the chart as a major problem parameter. Feedwater pH's have historically been a problem for the unit but recently have shown significant improvement. This is attributable to measuring equipment changes made recently. For this reason, it is not necessary to look further at this parameter.

Pareto Analyses: Weston 2

Figure 8 is the Pareto Diagram for W2. The six causes identified from the individual parameter run charts show up in the top ten causes from the Pareto. As seen for W1, some parameters in these ten have improved recently due to changes made by the laboratory group. The improvements in feedwater and boiler water pH are attributable to the same reason as for W1 (improved instrumentation). In addition, boiler water phosphate control has also improved. Since phosphate feed rate decisions are made in part on boiler water pH requirements, improvements in pH measurement technique will be reflected in the ability to maintain proper phosphate residual.

Cause and Effect Analyses

Having determined by run chart and Pareto Diagram analyses those parameters that contribute most to the problem, the next step is to examine each of these parameters individually to discover the reason or reasons each presents difficulties. Because these parameters are really outputs of the process described above and results of a process are usually attributable to a multitude of causes, cause and effect relationships can be identified.

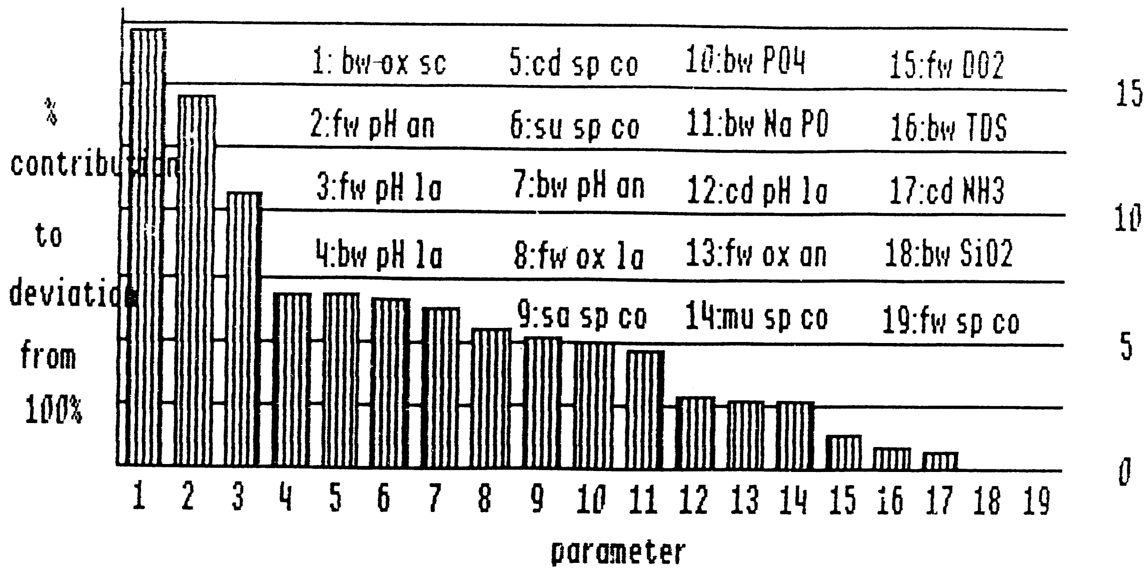

Figure 7. Weston 1 individual parameters

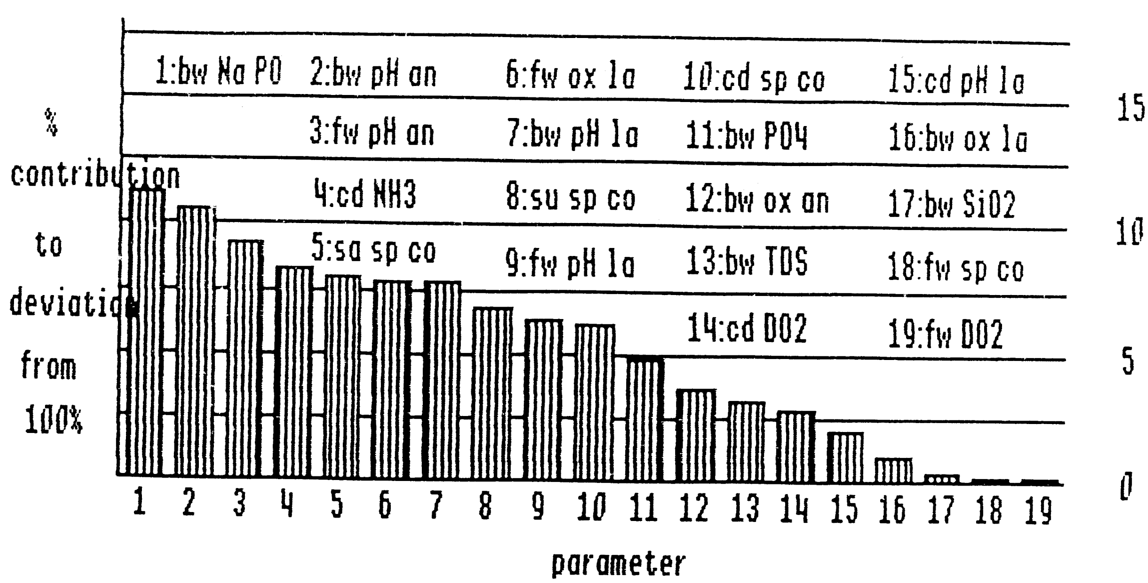

Figure 8. Weston 2 individual parameters

Typically, 80% of difficulties in keeping these parameters in limits can be attributable to 20% of the possible causes. This means, for these parameters, only one or two causes per problem parameter need to be addressed. These relationships can best be learned and presented in fishbone (or cause and effect) diagrams as illustrated in Figure 9.

<u>Boiler Water Sodium to Phosphate Ratio</u>

Figure 9 is the cause and effect diagram for boiler water high sodium to phosphate ratio. The two problems (for W1 and W2) are combined into one chart because the ratio is high for both and the causes are similar. The right most box on the chart indicates the problem. The other three boxes show causes which can contribute to the problem. The sodium to phosphate ratio is (as the name implies) the sodium concentration divided by the phosphate concentration. Phosphate is relatively easy to measure directly, but sodium concentration is obtained indirectly by pH measurement. Therefore, the three conditions which may lead to problems with high sodium to phosphate ratio are high pH, low phosphate, and improper ratio calculation. The laboratory staff derived suspected causes for this problem and all other problems by close examination of the monthly chemistry reports looking for correlating data, and by brainstorming sessions between laboratory attendants and operators. The latter method is extremely valuable, as these people have everyday experience with the process and thus are in the best position to understand it.

After consideration of all potential causes listed in Figure 9 the most likely cause as determined by the laboratory attendants and the Plant Chemist is an improper mix of sodium phosphate types in the feed tank. The chemistry group mixes a combination of tri- and disodium phosphate to provide a phosphate residual which reacts with hardness impurities such as calcium and magnesium to prevent scaling. Trisodium phosphate (TSP) also has the capability of increasing boiler water pH. Too much TSP though, and the sodium concentration goes too high, pushing the sodium to phosphate ratio over the limit.

Another possible cause (though not as likely as the phosphate blend) is a pH increase caused by the oxygen scavenger added. The scavenger contains both nitrogen (capable of increasing pH by formation of ammonia) and carbon (capable of reducing pH by formation of carbon dioxide). Because these effects are likely to counter one another at the low residuals carried, it is unlikely degradation of the oxygen scavenger is contributing to problems with the sodium to phosphate ratio.

Weston 1

Boiler Water Oxygen Scavenger. In addition to sodium to phosphate ratio, high boiler water oxygen scavenger concentration is a problem for W1. Figure 10 is the cause and effect diagram for this condition. The limit is set at 500 parts per billion (ppb) oxygen scavenger in boiler water based on previous experience with a different oxygen scavenger (erythorbic acid) which contained no nitrogen and therefore tended to suppress pH. The laboratory group kept this limit even after switching scavengers to methyl ethyl ketoxime (meko).

The Plant Chemist based the 500 ppb limit on experience with erythorbic acid. Meko is much more resistant to degradation in W1 than is erythorbic acid, based on boiler water pH, phosphate consumption, and presence of meko in the steam. Because of this, the concentration of meko tends to build in boiler water and increases above the 500 ppb limit, whereas erythorbic acid tends to degrade.

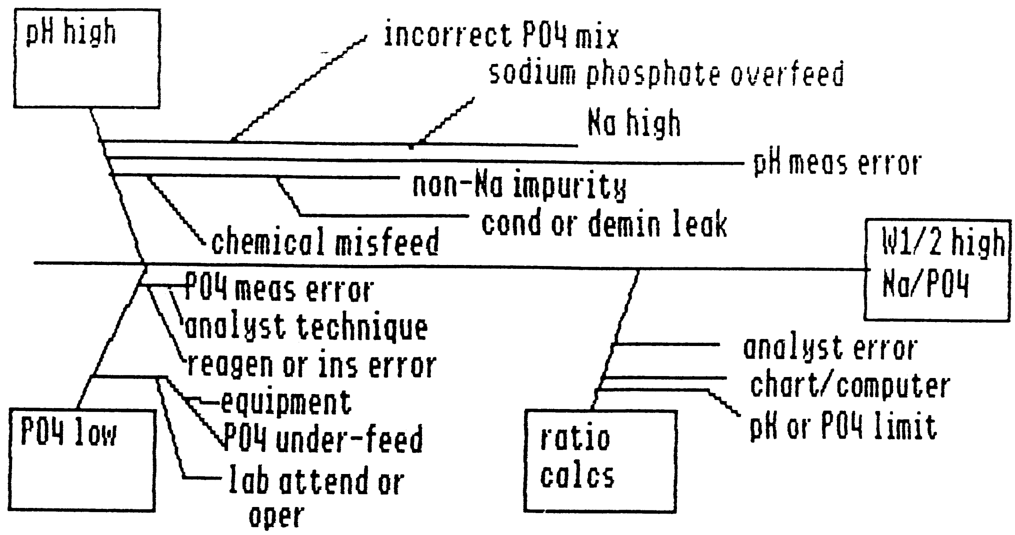

Figure 9. W1/2 Cause and Effect for Boiler Water Na/PO4

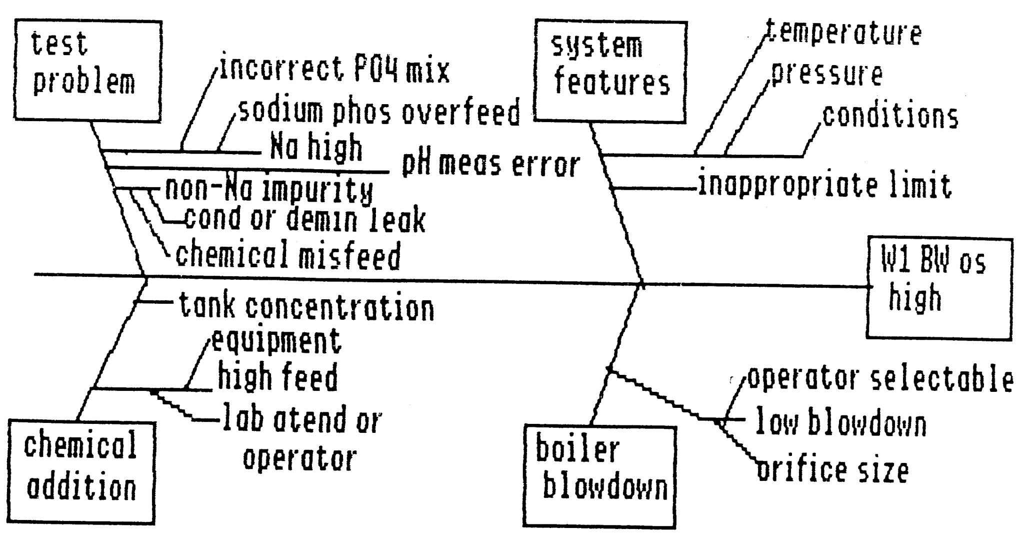

Figure 10. W1 Cause and Effect for Boiler Water Meko

Weston 2

Condensate Ammonia. High condensate ammonia concentration is a problem associated with W2 only. The cause and effect diagram for this problem is shown in Figure 11. Since ammonia is not added to condensate, this impurity must either be entering the system with other additions (such as makeup water, phosphate feed, oxygen scavenger feed, or condenser leakage), being formed by chemicals added, or caused by a test problem.

Tests of makeup water and chemical solutions in dilution tanks revealed no ammonia. In addition, there were no condenser leaks, as other parameters which go up during leaks (such as condensate cation conductivity) have not also increased. Figure 12 shows the correlation between feedwater meko concentration and condensate meko concentration. Since meko contains nitrogen, it is possible that some meko is converted to ammonia under high temperatures and pressures. The graph shows there is at least a weak correlation between the two. In addition, when ammonia concentrations between W1 and W2 are compared the W1 concentrations are found to be much lower than the W2 concentrations. If the hypothesis that meko forms ammonia under elevated temperatures and pressures is true, then the ammonia concentration would be expected to be higher for W2 than W1, as W2 operates at 1450 pounds per square inch gauge (psig) pressure while W1 operates at only 850 psig. Indeed this is the case and supports the hypothesis.

In addition, the laboratory group has experienced problems with the ammonia test on W2. Specifically, interferences have presented difficulties. An interference is a chemical (other than the one tested) which shows up as additional concentration for the chemical being tested. For instance iron is an interference on the meko test. The presence of iron causes the test result to be higher than it actually is. In the case of W2 condensate ammonia

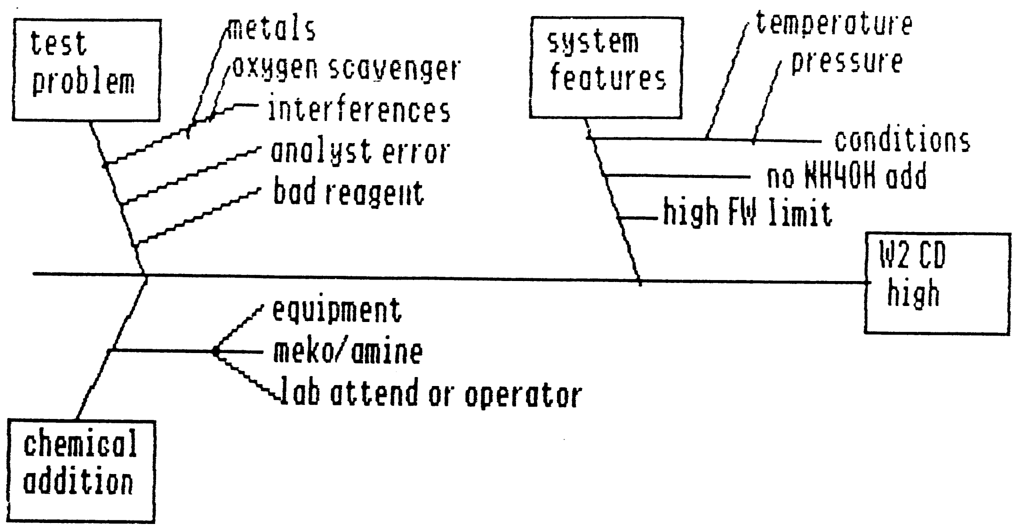

Figure 11. W2 Cause and Effect for Condensate Ammonia

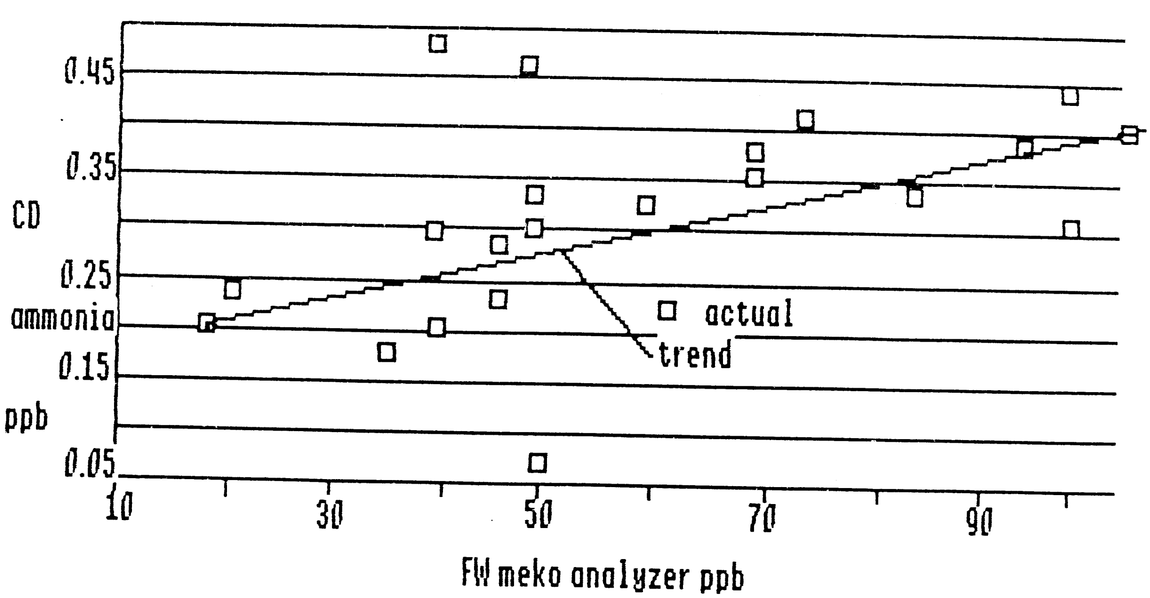

Figure 12. Weston 2 FW meko verses CD ammonia

testing, the laboratory group suspected (based on several test methodologies used) that meko or some of its by-products show up as interferences on the ammonia test.

Condensate Specific Conductivity. For W2, high specific conductivity in condensate is also a problem. Figure 13 is the cause and effect diagram for this condition. The potential causes identified for this are analyzer difficulties, chemical addition difficulties, operator error, and system features. The conductivity analyzer is very simple. It simply measures the current that can be conducted through water. The laboratory attendants checked the operation of the analyzer by measuring conductivity of a water sample in the lab. They found the results to be in agreement with the field instrument. Therefore the problem here does not rest with the analyzer.

Considering chemical addition, the only chemical added which could contribute to condensate conductivity is meko. This chemical is not added to excess though, since the meko residuals are low. Because meko residuals are generally low, it follows that the operators are doing a good job of maintaining proper chemical addition tank levels. Therefore, the cause does not rest with chemical addition equipment or operators.

This leaves system features. Due to the high temperatures and pressures as described above for the condensate ammonia problem, it is likely that ammonia manifests itself as high specific conductivity as well as high ammonia residual. This is true for two reasons. One is that ammonia solutions are very good electrical conductors. It takes only a small amount of the chemical to increase the conductivity substantially. The second reason is that the staff has not seen a corresponding increase in cation conductivity. Cation conductivity is measured identically to specific conductivity except that the sample is first passed through a resin column which removes all cations (such as ammonia). Hence, high ammonia residuals could cause increased specific conductivity without also causing high cation conductivity. This is the case.

Feedwater Oxygen Scavenger. Another problem for W2 is feedwater oxygen residual low. Figure 14 shows the meko residual for both analyzer and laboratory tests over time. It is evident that the concentrations trend together but also the laboratory number often goes to zero, whereas the analyzer value rarely goes to zero. The problem then is mostly of zero concentration values obtained in the laboratory.

Figure 15 is the cause and effect chart derived to address low meko residuals as measured in the laboratory. The potential problem areas are system features, operators, chemical addition equipment, and test problems. With regard to system features, areas that may impact the residual are sampling problems, air leakage, and load changes. Air leakage can be dismissed, as it has not changed and is quite low. Sampling difficulties are probably not at fault, as other parameters (such as dissolved oxygen) measured at this location are behaving properly. Load changes (that can change the amount of air leakage and hence meko consumption) do not seem to affect meko when load is compared to meko concentration.

If the system is not receiving enough meko because of chemical addition equipment malfunction or operator error, it should show on the trend chart for meko consumption. Over a seven month period, the gallons of meko added per hour of operation ranged from 0.0018 to 0.0068 with no clear correlation between low gallons per hour and low concentration. Therefore, this is not likely the most probable cause of low feedwater meko.

What remains are test problems. The laboratory attendants utilize a commercially available test kit called a reductant test. The kit contains

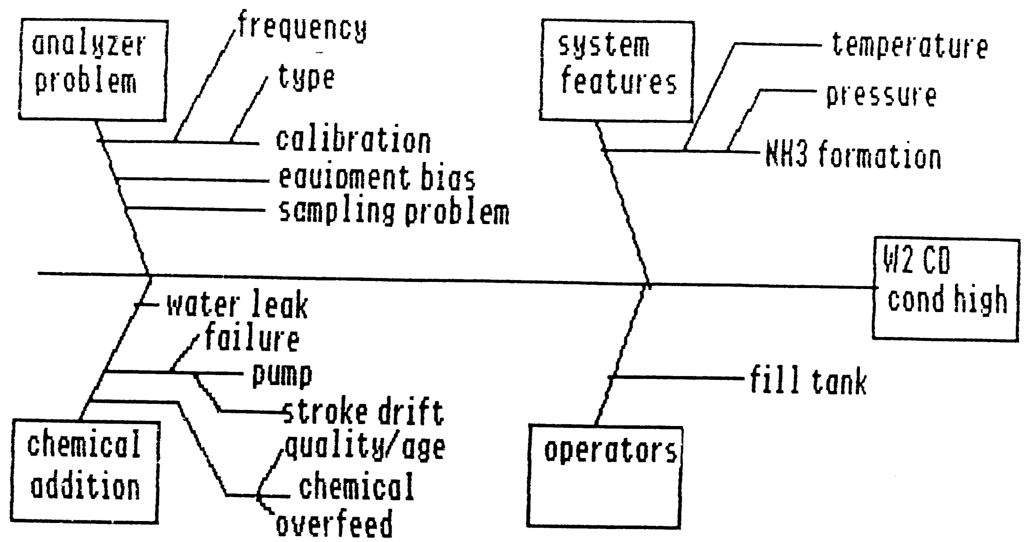

Figure 13. W2 Cause and Effect for Condensate Conductivity

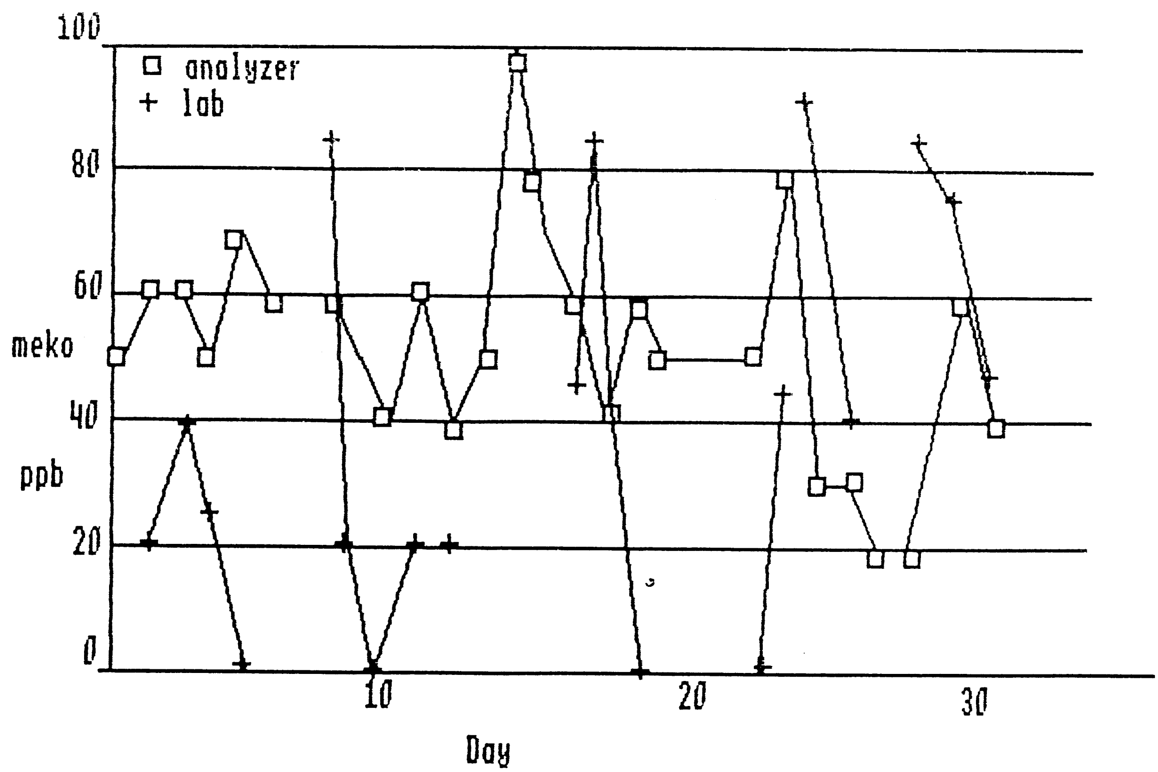

Figure 14. Weston 2 January 1990

several powdered reagents which are contained in pre-measured pillows. One possible source of test variability and low detectability could be variances in the amount of the reagents in each pillow.

Steam Conductivities. The final problem to be analyzed for W2 is high saturated and superheated steam conductivities. Since there is a fairly high degree of correlation between the conductivities, these problems can be treated together. Figure 5 shows the correlation. The coefficient of correlation squared is 0.724.

Figure 16 is the cause and effect diagram for the high conductivities. Among the causes listed, the most likely reason is excess meko in boiler water. This falls under the chemical addition section in the diagram as meko/amine. As meko is volatile, it is possible (and indeed provable by residual measurement) that some meko and meko breakdown products are carried from boiler water into steam produced by the boiler and superheater. This carry over will contribute to conductivity. This effect is also in agreement with the contention that parameters that are a function of temperature and pressure are more likely to be a problem for W2 and not W1 due to the temperature differences between the units. Indeed it is interesting to note that even though the two units are chemically treated in nearly identical fashion, W2 has more "problem" parameters than does W1.

If the conductivity is truly related to meko concentration, a correlation should be noted. Figures 17 and 18 are saturated steam conductivity and superheated steam conductivity respectively versus feedwater meko concentration. Additionally, these graphs show the linear regression for steam conductivity versus meko concentration. Both lines show positive correlations that indicate in general the conductivity will increase as meko

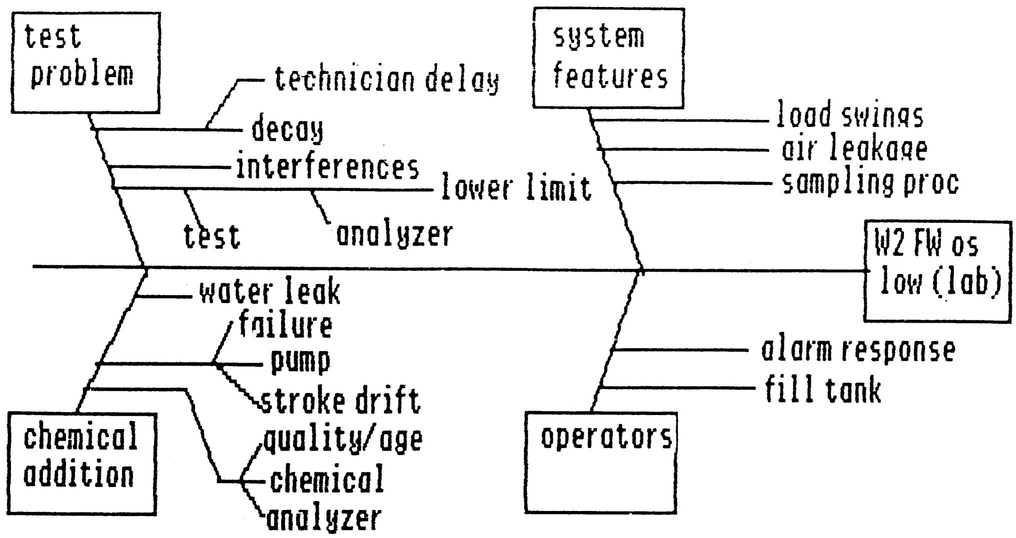

Figure 15. W2 Cause and Effect for Feedwater meko

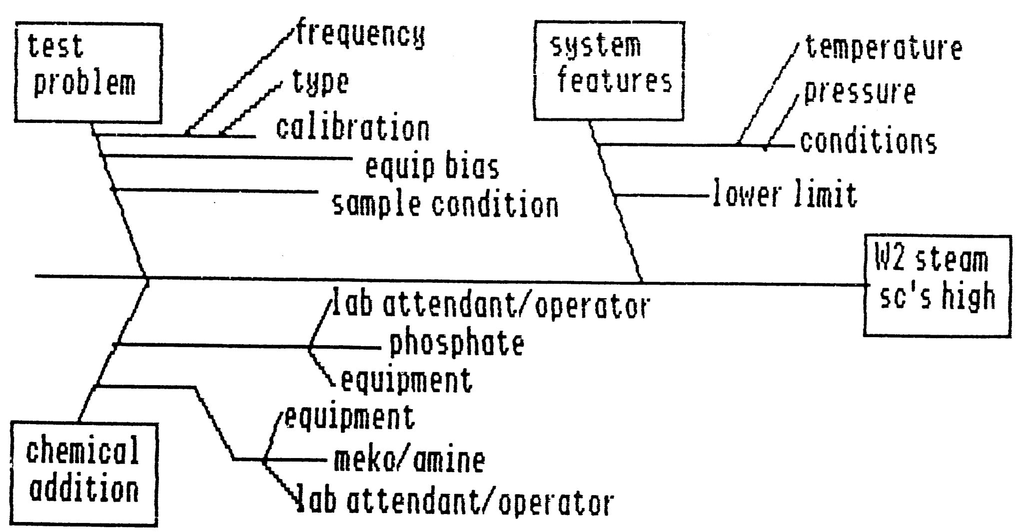

Figure 16. W2 Cause and Effect for Steam Conductivities

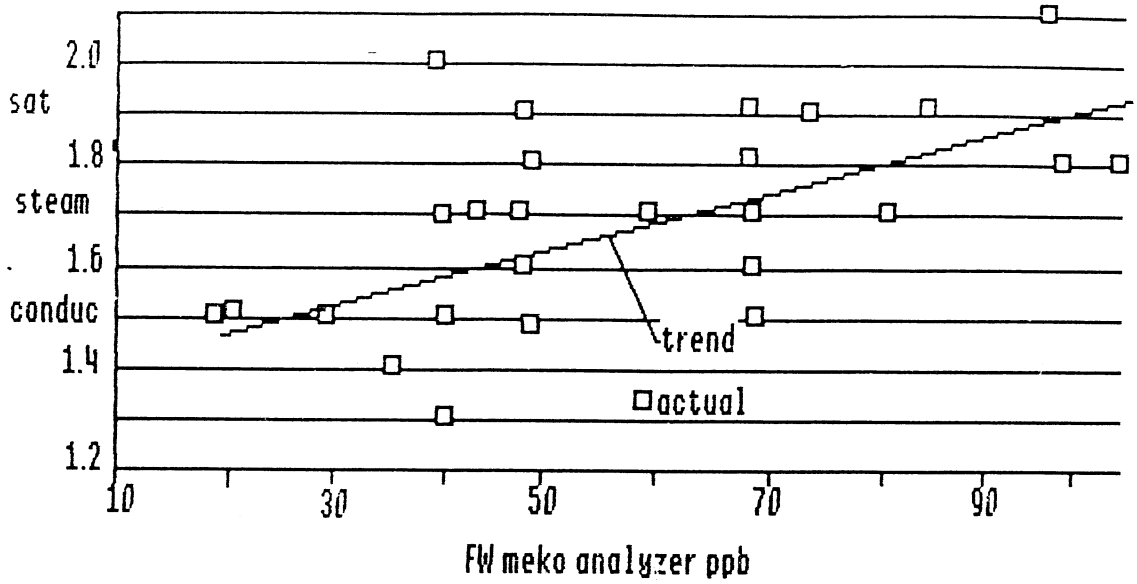

Figure 17. W2 FW meko versus sat steam conductivity

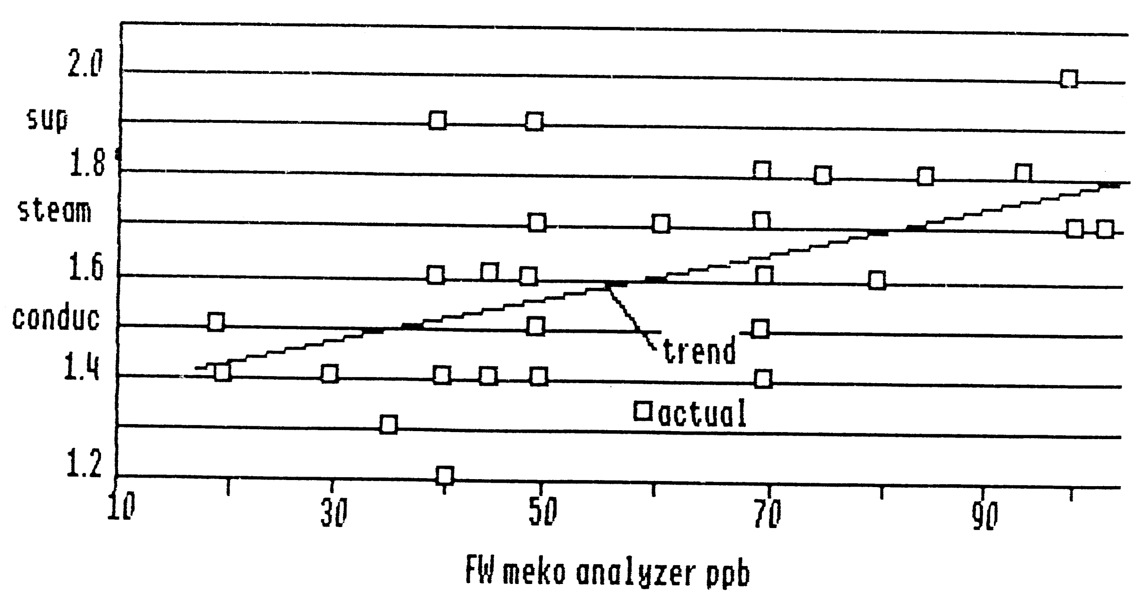

Figure 18. W2 FW meko versus sup steam conductivity

feed into the boiler increases. R^2 for Figure 17 is 0.380 and for Figure 18 it is 0.330. Therefore, the significance of elevated feedwater meko concentration as an explanation for elevated steam conductivities is less than 40%. As the correlation is not particularly "tight" there are other factors at work.

Here can be noted one of the paradoxes of boiler water chemistry, that is in some instances a situation may call for less of one chemical to be added to meet one desired range but more of the same chemical to meet another desired range. In this case, the feedwater meko residual is low (calling for additional meko feed) but the steam conductivities are high (calling for less meko feed). The challenge is to figure a compromise solution that works.

SECTION 5

ANALYSIS OF POTENTIAL SOLUTIONS

General

The laboratory staff has found (through statistical analyses and data review of historical chemistry results at Weston) that the problem of maintaining a high percent in limits of parameters measured can be reduced to just six of the 38 parameters routinely collected. These parameters, as listed above in the analysis section are boiler water oxygen scavenger concentration high (W1), high sodium to phosphate ratio (W1 and W2), high condensate ammonia concentration (W2), high specific conductivity (W2), low feedwater oxygen scavenger concentration (W2), and high steam conductivities (W2). This section covers potential solutions to these problems encompassing the four managerial functions of planning, organizing, leadership, and control for each of the problems listed above.

Due to the very technical nature of the problem, most potential solutions address the planning area, specifically commitment of resources. The other functional areas are covered though. It would be difficult to assure appropriate commitment of resources without addressing control, leadership, and organization.

Boiler Water Oxygen Scavenger

There are several planning-type solutions available for the high boiler water oxygen scavenger problem. First, the laboratory could attempt to control the feedwater oxygen scavenger concentration to a lower value. This would have the effect of reducing the amount of chemical that is delivered to the boiler. In turn, the concentration of the chemical in the boiler would be reduced.

Second, the oxygen scavenger type could be changed. If the laboratory were to utilize a chemical not resistant to degradation, the concentration of the chemical in the boiler would stay close to zero. Another idea might be to choose a more volatile chemical which would leave boiler water with the steam produced. The laboratory has experience with several alternative oxygen scavengers. The laboratory group can review this data regarding concentration experienced in boiler water and impact on other system parameters.

Third, the problem may rest with the test performed for concentration determination. If the current technique is subject to interferences, for instance, the laboratory technicians may actually find higher concentrations than are indeed present. Using another type analysis could eliminate this problem.

Fourth, the instrument group could install an automatic oxygen scavenger feed control arrangement. This device utilizes a feedwater concentration determined continuously by instrument as a signal fed to a controller on a chemical metering pump. The amount of chemical added is then controlled automatically. This would help prevent excess chemical in the boiler by eliminating over-feed situations that occur under manual control.

The fifth planning type solution is installation of blowdown control. Blowdown is a small boiler water stream taken from the boiler and discarded. Its function is to control impurity levels in boiler water. Currently, the system has continuous blowdown metered at a set rate by an orifice. Changing blowdown rate involves a mechanic physically removing the orifice plate from the blowdown pipe and replacing it with a plate containing a different orifice diameter. This procedure can take hours, and the new blowdown rate may not be appropriate. The addition of a calibrated blowdown valve would give the laboratory much flexibility regarding flow rates.

Lastly, the laboratory could set a higher allowable boiler water oxygen scavenger concentration. This could only be done after the laboratory staff thoroughly reviews the impact elevated concentrations have on other system parameters. Since the Plant Chemist determined the current limit while the system operated with a different type oxygen scavenger, this evaluation would certainly be of value.

Two organizational changes present potential solutions to the boiler water oxygen scavenger concentration as well. First, the Plant Chemist could require the laboratory attendants to attend to the maintenance of appropriate chemical concentration in the feed tanks. This gives complete responsibility for correct concentration to one department and probably to one individual.

Second, the laboratory attendants may be experiencing a problem with analytical technique. The Plant Chemist could make this determination by comparing results obtained versus which technician performed the test. If the Plant Chemist discovers a problem, management could institute additional training or might consider personnel reassignment.

Boiler Water Sodium to Phosphate Ratio

The next problem is high sodium to phosphate ratio at both W1 and W2. Two control type solutions are appropriate. The first would be to make use of control charts. This would basically be computer generated trend graphing with statistically derived warning and control limits. The laboratory attendant would simply input the ratio data into the computer on a daily basis, request the control charts to be generated by the software, and watch for developing trends. When the parameter drifted to the warning limit range, management could be consulted for suitable action or preferably the laboratory attendant could take corrective action.

Secondly, the laboratory group could implement a rigorous quality assurance program for pH and phosphate analysis. This would help only if the problem with the ratio parameter is related to analyses difficulties. The laboratory staff does not currently perform quality control in the form of duplicate and spike analysis for routine testing.

In the leadership area, another potential solution would be to stress the importance of this parameter with the laboratory attendants. As mentioned earlier, maintenance of this parameter within limits helps reduce boiler corrosion by keeping free caustic or free acid from forming. Management could best address this by reviewing the trend data on a daily basis with the laboratory staff. During these sessions, management can praise for achievement of good control or make suggestions for better control.

Utilizing laboratory personnel for maintenance of feed tank chemical for phosphate is an organizational type solution. The reasoning behind using laboratory staff for tank fills is similar to that presented above for oxygen scavenger.

Depending on the nature of the problem, the Plant Chemist could implement any or all of four potential resource commitment solutions. First, the instrument department could install automatic control of phosphate addition. This would work identically to the system described above for oxygen scavenger chemical addition. Laboratory control over phosphate residual with this system would be much better than the current practice of once per day manual feed rate adjustment.

Second, if the problem is related to impurities in the phosphate added, the laboratory staff could consider switching suppliers. Before implementing this change, the staff would test to determine the status of the current product used. Many companies are moving to sole source suppliers for the very purpose of elimination of problems like this. WPSC has not yet implemented such a practice.

Third, the phosphate feed pump (particularly for W2) is prone to breakdown. A potential solution is replacement of this equipment. Additionally, the Plant Chemist could consider installation of an on-line spare.

Fourth, the maintenance group could install the blowdown control described above. This control would increase, to a great extend, the ability of the laboratory staff to maintain correct phosphate residual in boiler water. Since this is one of the components in the sodium to phosphate ratio, the laboratory group would keep the ratio in limits a greater percentage of the time.

Condensate Ammonia

The next problem is high ammonia concentration in W2 condensate. As mentioned above for the sodium to phosphate ratio, one part of a potential solution is for management to stress the importance of careful test technique, use of non-expired reagents, and occasional blind standard testing. This Plant Chemist can do this through joint review of results with the laboratory attendants and exhibition of concern . In addition to this directional approach, management can also apply one or more of the following planning solutions.

First, the laboratory could switch test methodology. This relates to the interference problem discussed earlier. Independent testing organizations have already developed several different tests for ammonia concentration determination.

Second, the group could discontinue or reduce the application of the oxygen scavenger. Since the majority of ammonia is formed as reaction or degradation by-products of this chemical, by reducing the presence of oxygen scavenger the laboratory staff would also reduce the ammonia concentration. Of course, reduction of the oxygen scavenger might have other less desirable results.

A third potential solution is for the Plant Chemist to allow an increase in the allowable ammonia concentration. Like any change in allowable concentrations, the staff would need to study the impacts this change might have on corrosion rates and other parameters before implementation. This evaluation is particularly important due to ammonia's severe corrosive effect on copper coupled with the large number of copper bearing components in the system.

Fourth, the staff might change the type of oxygen scavenger used. Other chemicals are more resistant to thermal degradation than the scavenger currently applied at Weston. The more resistant the chemical, the less ammonia produced.

Fifth, as discussed above, the instrument group could install automatic control of scavenger feed. This would have the effect of elimination of overdose situations. Overdoses can cause increased levels of ammonia.

Another potential solution (related to problems in test methodology) is for the plant to utilize an independent laboratory for ammonia analysis. This is an organizational style change. Use of this solution could save considerable development effort for the Weston staff to find and implement a test that works.

Condensate Specific Conductivity

Increased ammonia levels for W2 are the likely cause for the next problem, that being high condensate specific conductivity. The Plant

Chemist can consider the potential solutions proposed to correct high ammonia concentrations as solutions to high conductivity because the problems of high conductivity and high ammonia are closely related. The laboratory group should contemplate reducing, eliminating, or replacing the scavenger chemical. Again, these techniques reduce ammonia production which in turn would help keep conductivities lower.

In addition, the laboratory group could make certain equipment changes which would help. The staff could minimize overdoses by installation of automatic feed control, replacement of the metering pump, and/or the addition of another metering pump. The advantages of these changes are the same as discussed earlier for some of the other problem parameters.

Generally, the Plant Chemist has a more difficult task assigning specific problems with fouling or corrosion for elevated conductivities than for other parameters. This suggests it may be appropriate to consider increasing the upper limit on acceptable conductivity. Thus, changing the limits represents another potential solution.

Regarding control changes, management could consider closer monitoring of the amount of neutralizing amine added. Amines help keep system pH within range and therefore help reduce corrosivity. Amines also contribute to conductivity though. This control could take the form of trend charts and correlation charts (between amine addition and conductivity). Both laboratory staff and management would review these charts.

Management concern for the status of these key parameters is crucial to solutions to several of the individual parameter problems. Again, if the Plant Chemist takes the time to query staff and provides direction for corrective actions on a routine basis for this parameter, the staff is more likely to be able to maintain appropriate chemistry.

It is possible this problem is related to faulty equipment rather than chemical application. For example, if the steam condenser were leaking river water into the condensed steam, the impurities in the river water would indicate as elevated conductivity. Organizationally, plant management could consider restructuring the maintenance department to provide additional employees for condenser leak testing and repair.

Feedwater Oxygen Scavenger

As shown earlier, the Plant Chemist has traced the problem with low oxygen scavenger concentration in W2 feedwater to difficulties with the current test procedure. Due to the ability to react with oxygen, the attendants must test water samples containing these chemicals quickly after taking the sample. This helps prevent apparent low concentrations caused by reaction with atmospheric oxygen. Organizationally, the Plant Chemist must stress the need to test these samples immediately after taking them.

Another potential solution is to switch test methods. The current test, which is purchased as a package, may simply not be sensitive enough to measure or detect the very low levels of this chemical the laboratory staff maintains in the water. The test may be indicating zero concentrations when in fact some chemical is present. The laboratory could consider a non-patented test method, allowing the group to prepare the reagents themselves and helping to assure a high quality procedure.

As a third solution, the staff could change oxygen scavengers. A different chemical may be more detectable with current test methods. The attendant might also apply a new chemical at higher (and more easily detectable) quantities.

Steam Conductivities

The final problem is high steam conductivities for W2. As noted above, this problem is most likely due to volatilization of oxygen scavenger or phosphate from boiler water into the steam. From a control function viewpoint, one potential solution is to implement a procedure for laboratory attendants to take corrective action such as increasing blowdown rate when the impurity levels are increasing in boiler water. Since the current equipment makes this very difficult to implement, the laboratory group would effect this solution in conjunction with blowdown equipment replacement.

It is possible this problem is related to the analytical equipment used for conductivity determination. The steam sampled is nearly 1000 degrees Fahrenheit. Between the sample point and analysis, a heat exchanger condenses and cools the water. Since the sample is still boiling during analysis, the service is fairly severe for the conductivity analyzers. If this severe service impacts the values determined by the analyzers, it could be of value for the Plant Chemist to review better conditioning of the samples prior to analysis.

If the lab staff determines that increased conductivities are related to boiler water phosphate concentration, they should examine their ability to control phosphate concentration. Currently, the attendants manually measure (once per day) the phosphate concentration and make one feed rate change per day. Given load changes and varying steam production requirements during each day, the practice of once per day adjustments to feed rate may not be enough to prevent occasional overdoses. Automatic control of phosphate feed at W2 in combination with new metering pumps would address problems with feed rate.

In addition to these control and resource allocation changes, management must consider leadership factors possibly contributing to this and other problems. Communication of the importance of proper control and motivation of the laboratory staff by delegation of use of control charts could be valuable tools for management to direct activities of the staff to take appropriate corrective actions. Suggested changes to treatment styles and control techniques offered by laboratory attendants could be an added benefit of delegated responsibility. Those people closest to the work are too often ignored as sources of ideas for improvement to the very processes with which they are most familiar. This suggestion applies to all the individual parameter problems. As an example, the laboratory staff has credit for many of the potential solutions listed in this section.. While the processes will improve after implementation of some combination of the suggestions contained in this section, it is important to realize most processes require continuous improvement. For this reason it is imperative for plant management to continue to encourage suggestions for and implementation of quality improvements from employees.

SECTION 6

THE RESOLUTION

General

As noted above, several of the problems share common proposed solutions. The more valuable proposed solutions impact several of the problem parameters. For example, the Plant Chemist can apply several leadership changes to all parameters. It would be of great value for the Plant Chemist to nurture good daily communication with all laboratory staff. This would allow the Plant Chemist to get the most up-to-date status of problem parameters as well as serve as an opportunity to exchange suggested treatment changes. The Plant Chemist should encourage the staff to make suggestions on both technical aspects and personnel issues.

Moving some of the responsibility for chemistry results to those employees working routinely with its maintenance serves two functions. First, it should improve department efficiency and results by more fully utilizing the personnel resources available. Second, management practice has long been not to consult employees on technical or managerial matters. Paradoxically, the company hires intelligent independent thinkers as determined by written pre-employment examinations and interviews. The removal (by management practice) of responsibility and opportunity to apply creativity has affected employee morale at Weston, as evidensed by union grievances submitted against company policies. By using the consensus style decision making process, the employees will be "empowered". This in turn will reduce problems with morale and increase the groups' work quality. Where consensus technique has been used at Weston (the instrument and control shop), morale has improved as admitted by the technicians in the group and by other plant employees' statements.

Another solution common to all parameters is appropriate alarm response by those running the plant (shift supervisors) when management is not present . Since resources are not available to maintain laboratory coverage on a 24 hour basis, the group depends on proper operator action to a large extent. Plant management needs to review the history of operator response as well as review current alarm response guidelines.

This leads to common solutions centering around control. The ability to continuously monitor pH and oxygen scavenger residual has only been available for 1-1/2 years. The lab staff has not yet prepared a suitable alarm response procedure. Although the laboratory has established standards (parameter ranges) and has methods for measuring performance against these standards (continuous analysis), it does not have a means to direct corrective action during off hours. An alarm response procedure and appropriate training would correct this deficiency.

The Plant Chemist should consider the merit of computerized trend analysis as another control technique. By restricting this technique to only problem parameters, the Plant Chemist will keep additional work load to a minimum. The benefits include early detection of undesirable prevailing tendencies of parameter values, objective determination of conditions which would be considered in warning condition or out of control, and a communication aid for group discussions. All members of the laboratory staff have considerable personal computer (PC) experience with a variety of software packages. In addition, the laboratory will shortly receive its own dedicated computer. Management would need to commit additional resources to the time required for data input and interpretation and to acquisition of suitable software.

Among the common solutions in the planning functional area is test switching. The laboratory group needs to find new methodology for both oxygen scavenger concentration and ammonia concentration determination. The oxygen scavenger used at Weston is a patented proprietary product available from but one vendor. The vendor currently has a new test method under development. It is imperative the Plant Chemist ensures Weston receives this procedure as soon as it becomes available. It may even be possible for the staff to get the test prior to its commercialization due to the strong working relationship between WPSC and the vendor.

Along these same lines, the staff should implement a new test for ammonia concentration determination. Because ammonia use is not patented, several tests exist in standard test methodology literature. The laboratory attendants should try these tests to discover one which solves the problem with interferences.

Regarding future commitment of resources, management should ensure that automatic control of oxygen scavenger feed, new metering pumps, and calibrated blowdown control all be installed (for equipment stocked at Weston) or budgeted for installation as soon as possible. Automatic control prevents over- and under-dosages, which lead to problems discussed above. The pumps have historically been a problem due to frequent failures. New pumps with on-line spares will prevent pump outage difficulties. Installation of calibrated blowdown control will give the laboratory attendants as great a measure of boiler water chemistry control as enjoyed at Weston unit 3.

Specific

Boiler Water Oxygen Scavenger

Several parameters require specific solutions. The first of these is adjustment by the Plant Chemist of the required range for W1 boiler water oxygen scavenger. The laboratory group currently attempts to maintain this concentration at less than 0.5 ppm. A better range for this application is less than 1.0 ppm. A review by the Plant Chemist of previous situations when the concentration was in the 0.5 to 1.0 ppm range showed no adverse effect on other system parameters.

Second, the maintenance group should replace the phosphate metering pumps and add an on-line spare. The reasoning for this is similar to that discussed above for oxygen scavenger. In this case though, only boiler water phosphate concentration and boiler water pH are affected.

Third, the laboratory attendants need to be aware of the criticalness of timely analysis of oxygen scavenger residual. By analyzing immediately after sampling, the lab attendants may help eliminate some of the problem with low residuals in feedwater.

Potential Solutions not Implemented

Many potential solutions as listed in the in the previous section should not be implemented by the plant. The first of these is switching chemicals. This may have benefits in terms of conductivity and residuals, but the staff has determined that the current chemical reduces corrosion. This is because corrosion product transport has decreased as indicated by iron and copper concentrations in feedwater measured by lab staff. For this reason, the benefits of switching do not outweigh the costs.

Another solution not recommended is lowering oxygen scavenger dosed or eliminating its use altogether. Changes like these are detrimental for reasons similar to those given for switching products.

The laboratory should also not reduce neutralizing amine feed. Reducing feed would have the negative impact of reducing condensate and feedwater pH. Corrosion in the pre-boiler section would increase.

In addition, operators should continue filling chemical feed tanks. The benefit of complete laboratory control of chemical feed would be offset by instances where chemical tanks would empty and no one would be available for refill. For this reason, the operations group should continue to maintain the oxygen scavenger/neutralizing amine and phosphate tanks.

Assigning laboratory tasks based on previous results is also not a good idea. This would discourage depth of experience for the small group and may also serve as a demotivating factor as personnel may sometimes be subjectively evaluated. The group would also lose the benefit of application of several perspectives on the same problem.

Rigorous application of quality assurance to more laboratory test procedures does not survive a cost/benefit test. Because much of the laboratory work involves straightforward test methodologies, the laboratory group would not gain any considerable advantage by adding extensive quality assurance measures. Annual review of procedures and tests of standard solutions as performed currently by the laboratory attendants should continue to suffice.

Tests performed on chemicals received show no need to replace vendors. In fact, having found vendors that supply high quality products in a timely manner, it is in the company's best interest to continue in a long-term working relationship with these sole source suppliers.

At this point, management cannot justify installation of automatic phosphate feed control. As part of the continuous process of quality improvement, the laboratory group should evaluate this need again after the laboratory implements the other changes as presented above.

Changing ammonia and conductivity limits are not recommended. The literature clearly shows 0.3 ppm maximum as a widely used guideline for copper bearing equipment. Conductivity guidelines are not available, but current standards have served well in light of turbine inspections. Another consideration is that the current limit should be achievable when the other solutions suggested above are in place.

Because several alternative tests are available, it is better the laboratory staff continue to perform ammonia testing themselves rather than send samples for outside analysis. The analysis cost of performing testing at Weston is lower than it would be using another laboratory and the results are available quickly. The Plant Chemist may need to reevaluate this if the laboratory cannot obtain proper results by switching tests.

Review of system chemistry related to condenser leakage by the Plant Chemist showed a vigorous condenser leak detection and repair program is not necessary. Problems with condenser leakage would normally show as increased cation conductivity and elevated sodium concentration. Neither of these parameters have increased to values that would indicate leakage.

Implementation of Solutions

Leadership solutions (to this problem) should focus on training. WPSC has a strong technical training curiculum offered to employees. The company offers some basic leadership skills courses. WPSC also offers courses covering quality through empowerment of employees . The laboratory staff needs continued technical training and additional "quality" empowerment training. The Plant Chemist requires technical, "quality", and leadership skills training to effectively manage the department. The Plant Chemist needs such leadership skills as empathy, group decision making techniques, ability to relate to all personality types, and a firm understanding of company policies. The company training resources should be utilized by laboratory staff and management to help solve any communication and motivation difficulties in the group.

Training should also be required for shift supervision. This training should revolve around system chemistry importance, details of parameter limits, and proper response by operations to parameters that move outside established standards. In effect, these training sessions will introduce the alarm response procedures to the operations group.

Implementation of control through trend analysis by the laboratory group is straightforward. This is true since PC hardware and software familiarity among the group is already available. What remains is for the group to purchase or design of an appropriate statistical software tool. Because laboratory group experience in application development is limited, the recommendation is to purchase a commercial program. There is an abundance of commercially available statistical process control software.

Technical management has the responsibility to require use of the package by the Plant Chemist and laboratory staff. Immediately upon starting use of the tool, the Technical Supervisor should begin daily review of the trend charts with laboratory attendants and the Plant Chemist. As the staff gains experience with generation of the charts and proper corrective actions to be applied based on information learned from the charts, the Technical Supervisor can reduce the review frequency.

Related to the development of the alarm response procedure, the Plant Chemist should design operator logs . These logs (filled out by operators) will list corrective actions taken in response to abnormal chemistry conditions. The Plant Chemist will then review these logs to ensure an action was taken and that the action was appropriate to the conditions.

The Plant Chemist should also continue to stress the importance of chemistry equipment installation with maintenance supervision. There is a tendency for the maintenance group to give these projects lower priority than other corrective or periodic maintenance duties due to the preventative nature of the changes and the limited size of the mechanical maintenance staff. By reminding the maintenance group frequently of the importance of the work, the Plant Chemist makes it less likely the work will be forgotten.

To implement the oxygen scavenger test switch, the laboratory staff should contact the chemical vendor to request the new procedure and appropriate reagents, and then practise with the procedure. The Plant Chemist should compare the results of using the new method against those obtained using current technique and results from the on-line analyzer.

Switching to the new ammonia test procedure should also be straightforward. Weston staff already is in possession of a number of alternative methods. The oxygen scavenger vendor or other utilities may provide some direction as to the best method. The staff would procure reagents, develop concentration charts, and put the test into production.

The allowable oxygen scavenger concentration change in boiler water at W1 can be implemented by the Plant Chemist in a memo to laboratory staff. Additionally, the Plant Chemist should update all logs and forms showing the old limit. The laboratory staff's changes to the alarm response procedure is critical.

The Technical Supervisor should place all new equipment suggested above in the upcoming capital equipment budget. Approximately one year after budget submittal is the earliest the lab staff could expect this equipment to be operational. For this reason, it is imperative the Technical Supervisor submit this equipment into the budget at the first possible opportunity.

Organizationally, management must review implementation of immediate testing requirements for oxygen scavenger. The effects on chemistry performance of one month rotation of the laboratory staff through the W1 and W2 laboratory should be reviewed by management as well and compared with data available for the permanent W1 and W2 laboratory position.

Costs and Benefits

The impacts of implementing the solutions listed above include both costs and benefits. Costs include time requirements for daily laboratory group meetings for discussion of results, development of the alarm response procedure, training on leadership technique and on appropriate alarm response, development of new tests, and installation of new equipment. The plant will also incur additional equipment cost .

The laboratory time requirements for putting into place daily computerized trend analysis will be extensive initially. This is due to learning curve requirements of laboratory staff, particularly regarding proper corrective actions. Initially, management will require much time for review with laboratory staff of the charts. As laboratory attendant experience with the system grows and the need for frequent review declines. the resources spent by the plant on implementing this solution will go down.

Overall, the company will experience benefits that outweigh the costs associated with implementation of these suggestions. The long term impact will be better chemistry control leading to reduced corrosion and fouling of equipment. This means the company will spend less resources for equipment replacement and repair. Down time expenses can be quite high when the costs of purchasing replacement power are factored in. A single outage can cost the company as much as $60,000 in replacement energy expenses alone (based on the loss of the Weston Unit 2). The costs associated with the solutions listed in SECTION 6 are $10,000 (training), $2,000 (procedure development), $7,200 (computer program), $1,000 (analytical test development and materials), and $4,000 (new chemical feed and control equipment). Avoiding just one unit outage as a result of these improvements would save more than all costs expected to be incurred if the plant implements all the suggestions listed above.

The extent to which management improves its decision making (through improvements such as discussed in this paper) will determine the extent to which WPSC will enjoy production cost reductions. As shown above, appropriate management decision making should yield better chemistry control. Improved chemisty control will lead to reduced production costs, giving WPSC a more competitive position in the upcoming era of utility deregulation.

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